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Music perception in children with Autism Spectrum Disorder

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Music perception in children with Autism Spectrum Disorder

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Résumé

Le trouble du spectre de l'autisme (TSA) est une maladie neurodéveloppementale complexe, caractérisée par des problèmes d'aptitudes socio-communicatives et par une perception sensorielle atypique, particulièrement dans le domaine auditif. Alors que de nombreux individus atteints par un TSA ont des troubles de la parole et des déficiences de communication, leurs capacités musicales sont souvent intactes, voir même meilleures. La musique est un moyen clef d'étudier la perception sensorielle chez les individus ayant un TSA. Toutefois, la perception de la musique chez ces individus n'est pas suffisamment bien comprise et reste floue. Cette étude visait à examiner la perception musicale des enfants ayant un TSA sur un éventail de tâches musicales en relation avec l'intelligence verbale et non-verbale, ainsi qu'avec l'âge et la sévérité des symptômes Les enfants ayant un TSA ont eu des résultats similaires aux enfants ayant un développement typique. Dans les deux groupes la perception musicale a augmenté avec le niveau d'intelligence et avec l'âge. Plus précisément l'intelligence non-verbale a été liée au discernement des tons mélodiques. Également, la perception du rythme a été améliorée avec l'âge. Il n'y a pas eu de relation entre le vocabulaire réceptif ou la sévérité des symptômes et la perception musicale chez les enfants ayant un TSA. D'une manière générale, cette recherche aide à mieux comprendre le traitement sensoriel chez les individus atteints d'un TSA et en particulier leur perception musicale. Par la suite, ceci peut favoriser la compréhension des différences individuelles et mieux définir le phénotype de ces individus. Ce travail peut orienter des études à venir sur les effets de la thérapie musicale en ce qui concerne les individus ayant un TSA. **Mots clés:** Autisme; perception, musique, développement.

Abstract

Autism spectrum disorder (ASD) is a complex neurodevelopmental condition that is characterized by difficulties in social and communication skills and restricted patterns of behavior, often involving atypical sensory perception, including in the auditory domain. While many individuals with ASD have speech and communication impairments, they often have preserved or even enhanced music skills. As such, music provides a key way to study sensory processing in ASD. However, music perception in ASD is poorly understood and research has yielded mixed results. The current study aimed to examine music perception across a range of tasks including melodic pitch, rhythm perception and memory in school-age children with ASD. To clarify individual differences we examined music perception in children with ASD as a function of verbal and non-verbal IQ, age, and ASD symptom severity. Children with ASD performed similarly to TD children in both a verbal IQ-matched sample and an age-matched group with a more representative range of IQ abilities ('non-VIQ-matched'). Music perception increased with cognitive ability in ASD and TD, and more specifically, non-verbal ability was related to pitch discrimination in ASD. Rhythm discrimination increased with age in both ASD and TD. There was no relationship between receptive vocabulary or social symptom severity and music perception in children with ASD. This research helps to better understand sensory processing in ASD in general, and music perception in particular. The study of sensory differences in ASD informs our understanding of individual differences and allows us to better define phenotypes in ASD. Finally, this work serves as a guide for future studies on the effects of music therapy in ASD.

Keywords: Autism, music, perception, development.

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ADI	Autism Diagnostic Interview - Revised
ADOS	Autism Diagnostic Observation Schedule
ASD	Autism Spectrum Disorder
BD	Block Design Task
EPF	Enhanced Perceptual Functioning
IQ	Intelligence Quotient
PIQ	Performance intelligence quotient
TD	Typical development
VIQ	Verbal intelligence quotient
MBEMA	Montreal Battery for the Evaluation of Musical Abilities
WASI	Wechsler Abbreviated Scale of Intelligence
PPVT	Peabody Picture Vocabulary Test
SCQ	Social Communication Questionnaire
SRS	Social Responsiveness Scale

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Introduction

An overview of Autism Spectrum Disorder (ASD)

Autism Spectrum Disorder is a complex neurodevelopmental disorder estimated to affect 1 in 68 individuals (U.S. Centers for Disease Control and Prevention, 2014). The male to female ratio is 3 males to 1 female (Loomes, Hull & Mandy, 2017). Core diagnostic features of ASD include significant difficulties in social communication abilities as well as restricted and repetitive behaviors. Recently, additions have been made to ASD diagnostic criteria to include atypical sensory processing (American Psychiatric Association, 2013). However, relative to studies on core ASD symptoms such as social cognition, limited work has been done on sensory perception in ASD and in particular in terms of auditory processing. While many individuals with ASD have impairments in processes required for speech perception, such as auditory filtering, phoneme categorisation, and multisensory integration (DePape et al., 2012), they often have preserved or even enhanced auditory-music skills (Ouimet et al., 2012) such as in pitch discrimination (Heaton, 2003, 2005**)** and pitch memory **(**Stanutz, Wapnick, & Burack, 2014). Thus, music provides a unique way to understand auditory processing in ASD, since music does not depend on verbal communication. Studying sensory processing can provide better ways to define individual differences in ASD and to refine sensory phenotypes. Accordingly, the present study sought to assess music perception across a range of music tasks in children with ASD versus typical development (TD), as a function of differing cognitive abilities, age and symptom severity. Our ultimate goal is to better characterize auditory perception in children with ASD so that this knowledge can guide auditory-based interventions to improve communication and social functioning in ASD.

Theories of perception in ASD: from vision to audition

Sensory processing is essential for navigating our multisensory environment. Various theories, mostly arising from visual research, have been put forward to explain atypical sensory perception in ASD. Based on findings from the visual domain, the 'Weak Central Coherence' theory (Frith, Happé & Happé, 2005) proposes that individuals with ASD have a strong detailed (or locally) oriented style of processing, but at the cost of impaired processing of whole (global) features. However, support for the Weak Central Coherence theory in auditory processing in ASD is not clear. A newer theory, the 'Enhanced Perceptual Functioning' model (EPF) (Mottron et al., 2006) also highlights enhanced local perception in ASD, but with intact global processing. Evidence for the EPF model comes both from vision and more recently from audition. In addition, the EPF considers the complexity of the stimulus and predicts superior processing for lower-level stimuli (e.g., pure-tone pitch discrimination) and diminished processing of more complex stimuli (e.g., speech in noise). In the present research, we will focus on the EPF model as it is a more recent and comprehensive model of ASD that extends across the visual and auditory domains and considers varying levels of stimulus complexity.

Music perception in ASD

Consistent with the EPF model, one example of enhanced processing in ASD comes from studies on musical perception in ASD. As a non-verbal model, music is a unique means to study auditory processing in ASD. However, studies on auditory-music processing in ASD are limited. Some research has highlighted enhanced music perception in particular for pitch processing in ASD. For instance, enhanced processing in ASD has been found in frequency discrimination (Jones et al., 2009), single tone pitch discrimination (Stanutz, Wapnick, & Burack, 2014; Bonnel et al., 2010; Heaton et al., 2008; O'Riordan & Passetti, 2006), and pitch identification (Heaton, Hermelin, & Pring, 1998). Enhanced processing has also been found in ASD in the detection of small pitch direction changes in interval tasks (Heaton, 2005), pitch categorization (Bonnel et al., 2003), disentangling pre-exposed pitch tones from chords (Altgassen et al. 2005), and contour identification (Jiang et al., 2015). Enhanced pitch memory has been reported in ASD for long-term melodic memory (Stanutz, Wapnick, & Burack, 2014), long-term pitch memory (Heaton et al., 2008), memory for unlabelled pre-exposed pitch tones (Heaton, 2003) and a greater incidence of absolute pitch in ASD (Bouvet et al., 2016; Mottron et al., 2013; DePape at al., 2012; Masataka, 2017). Evidence for preserved processing of auditory-musical and song stimuli in ASD have also been found at a neural level (Caria et al, 2011, Lai et al, 2012, Sharda et al, 2015).

However, not all studies have found enhanced musical perception in ASD versus TD. For instance, similar performance was reported between ASD and TD on tasks of melodic global-local perception (Foster et al., 2016), pitch direction discrimination (Germain et al., in revision), pitch identification (Altgassen et al., 2005), and in studies involving harmonic priming (DePape et al., 2012), music structure processing (Bhatara et al., 2013) or contour discrimination (Jiang et al., 2015). Individuals with ASD have also shown similar performance to TD children in auditory-motor rhythm synchronization (Tryfon et al., 2017), although some studies show that people with ASD have reduced specialization in categorizing simpler meters prevalent in Western music over more complex meters (DePape et al., 2012). This variation in performance across studies may be due to a range of factors such as a variation in the types of tasks used across the studies, and the different cognitive abilities, age and symptom severity of the ASD participants.

Overall, these findings highlight preserved auditory-music perception abilities in ASD, with some instances of better processing of pitch information. However, to better define auditory-music processing in ASD, further studies are necessary and particularly across a range of music perception tasks, and as as a function of cognitive ability, age and symptom severity of ASD participants.

Cognitive abilities and sensory processing in ASD

Individuals with ASD often show very different cognitive profiles (Kanner, 1972), with intellectual disability present in nearly half the ASD population (Charman et al. 2011). Even among those without intellectual disability, there is marked variability in the presentation of verbal and non-verbal cognitive profiles in ASD (Black et al., 2009; Charman et al., 2005; Farley et al., 2009; Joseph et al., 2002; Koyama, Tachimori, Osada, Takeda, & Kurita, 2007). The Wechsler intelligence scales, such as the Wechsler Abbreviated Scale of Intelligence (WASI), are a common tool to estimate an individual's general intelligence, which include both verbal and non-verbal intelligence measurements (Wechsler 1999, 2011). Verbal intelligence (VIQ) measures verbal reasoning abilities using the examinee's acquired knowledge of verbal concepts, whereas non-verbal or performance intelligence (NVIQ; PIQ) relies on the examinee's fluid reasoning abilities (Wechsler, 2011). Previous literature has shown that non-verbal IQ is usually highly correlated with concurrent verbal skills (Bono, Daley, & Sigman, 2004), but to date, the association between cognitive abilities and sensory modalities, such as auditory perception, remains unclear in ASD.

Greater receptive language abilities have been associated with improved auditory processing in TD (Grube, Kumar, Cooper, Turton, & Griffiths, 2012; Mayer et al., 2016), but whether this link translates to auditory perception and verbal skills in ASD is uncertain. For instance, no relation between pitch discrimination and receptive vocabulary was found in ASD (Mayer et al. 2016). An association has been highlighted between non-verbal skills and auditory skills such as pitch discrimination (Mayer et al., 2016), melodic discrimination (Stanutz, Wapnick, & Burack, 2014), and melodic memory ability (Heaton et al., 1998, Heaton, Williams, Cummins, & Happe, 2008; Stanutz et al., 2014). However, these findings have not always been replicated (Heaton, Williams, et al., 2008; Meilleur et al., 2015). Recently, we found a link between melodic pitch discrimination and non-verbal skills in children with ASD (Chowdhury et al., 2017), although the musical stimuli used in this study were not naturalistic (i.e., ecologically valid) and the participant sample did not include individuals with low IQ.

The effect of age on music perception in ASD

Differences in music abilities in ASD may be related to verbal and non-verbal abilities, but other variables such as age may also have a part to play. Recent work from our group suggests that auditory global-local processing in young children with ASD (6-8 years old) might develop differently from TD (Foster et al., 2016). In another study, fine pitch discrimination improved with age in TD children (5-14 years), but, in contrast it was enhanced in childhood and then stayed stable in children with ASD aging from 6 to 14 years old (Mayer, Hannent & Heaton, 2016). In addition, developmental differences have been found in ASD for auditory short-term memory which continues to develop to adulthood in TD, but stops prematurely in persons with ASD (Erviti et al., 2015). Some structural and functional neural differences are sensitive to age in ASD and TD for language and auditory processing brain regions (Floris et al., 2016; Groen et al., 2011; Keller et al., 2007; Lange et al., 2015; Lee et al., 2007; Wan et al., 2012). Overall, development in ASD seems to differ from TD for some features of auditory-music perception, and notably for fine-grained pitch processing. In order to better understand these developmental effects and how they affect music perception, additional work must examine performance over a range of music tasks.

The effects of symptom severity on music perception in ASD

Other than the effects of development on music processing, it is pertinent to consider how clinical severity may influence children with ASD's ability to perceive music. Examining these aspects can, in turn, help to better understand individual differences in ASD. Work on sensory-auditory perception and symptom severity in ASD is surprisingly sparse. Recently, a study showed a relationship between electrophysiological neural (EEG) recordings during an audio-visual task and symptom severity in ASD in children and adolescents with ASD (Brandwein et al., 2015). In this study, EEG stands out as a particularly sensitive measure to assess ASD symptoms because the behavioral reaction times of this audiovisual task did not correlate on their own with symptom severity, whereas the EEG signal during the task did correlate with severity. However, EEG responses and reaction times were not linked to responses on the Short Sensory Profile (SSP) (McIntosh et al., 1999), a parent-rated questionnaire for child's reactions, preferences, and tendencies when confronted with everyday sensory stimuli and situations (Brandwein et al., 2015). The possible association between music perception and ASD severity has not yet been explored. Findings on music perception related to clinical severity in ASD can guide future work on auditory-music focused interventions in ASD.

Study objectives and hypotheses

The objective of the present thesis was to better characterize auditory profiles by examining music perception across a range of music abilities in children with ASD versus TD, and to measure how music perception may vary based on cognitive abilities, age and ASD symptom severity. Taken together, individuals with ASD appear to have certain preserved or even enhanced music perception abilities, such as for melodic pitch and memory, whereas rhythm perception may be compromised (DePape et al., 2012). However, the effects of cognitive abilities, age and symptom severity on music perception in ASD remain unclear. In the present study, the Montreal Battery for Evaluation of Musical Abilities, a child friendly battery of music tasks involving "same-different" judgments for melodic pitch discrimination, rhythm discrimination and melodic memory was used to assess music perception.

Aim 1 of this research was to compare various aspects of music perception in ASD versus TD in terms of melodic pitch, rhythm discrimination, and melodic memory. Melodic pitch discrimination, rhythm discrimination and melodic memory were expected to be spared or even enhanced in ASD vs TD (Heaton, 2003, 2005; Stanutz, Wapnick, & Burack, 2014, Tryfon et al., 2017).

Aim 2 of this research was to examine the relationship between music perception with verbal and non-verbal performance on the Wechsler's Abbreviated Scale of Intelligence II (WASI-II) (Wechsler, 2013) in ASD versus TD. Receptive vocabulary was tested using the Peabody Picture Vocabulary Test 4 (PPVT-4) and included as a measure of verbal ability due to its high testing reliability with clinical populations affected by language and communication disorders such as ASD. More specifically, the PPVT-4 facilitates the evaluation of verbal ability in individuals with communication difficulties such as non-verbal children with ASD, because it does not require a verbal response in order to assess the vocabulary range of participants. While non-verbal ability should predict music perception ability (Luyster et al., 2008; Meilleur et al 2014; Chowdhury et al., 2016; Shah & Frith, 1993), previous work (Sharda et al., 2015; Eigsti & Fein, 2013; Lai et al., 2012; Bonnel et al., 2010; Jones et al., 2009; Heaton & Allen, 2009) suggests that verbal ability will not necessarily predict music perception ability in children with ASD.

Aim 3 of this research was to examine the potential relationship between age and music perception in ASD versus TD. Based on previous research, performance improvements are expected with age in ASD and TD (Germain et al., in revision; Foster et al., 2016; Peretz et al., 2013).

Aim 4 of this research was to examine the potential effects of symptom severity on music perception in children with ASD. Based on previous research (Brandwein et al., 2015) we expected that any relationship between severity and music perception would be in the direction of group differences in performance.

Abstract

Background: Autism spectrum disorder (ASD) is a complex neurodevelopmental condition that is characterized by socio-communicative difficulties and restricted patterns of behavior, often involving atypical sensory perception, including in the auditory domain. Despite these impairments, many individuals with ASD have preserved or even enhanced music skills. As such, music provides a key way to study sensory processing in ASD. However, music perception in ASD is poorly understood and research has yielded mixed results.

Methods: The current study aimed to examine music perception across a range of tasks including melodic pitch, rhythm perception and memory in school-aged children with ASD. To clarify individual differences, we examined music perception in children with ASD as a function of verbal and non-verbal IQ, age, and ASD symptom severity.

Results: Children with ASD performed similarly to TD children in both a verbal IQ-matched sample and a more representative range of IQ abilities ('non-VIQ-matched'). Music perception increased with cognitive ability in both groups, and non-verbal ability was related to pitch discrimination in ASD. Rhythm discrimination increased with age in both groups. There was no relationship between receptive vocabulary or social symptom severity and music perception in children with ASD.

Conclusions: This research helps to better understand sensory processing in ASD in general, and music perception in particular. The study of sensory differences in ASD informs our understanding of individual differences and allows us to better define phenotypes in ASD. Finally, this work serves as a guide for future studies on the effects of music therapy in ASD.

Keywords: Autism spectrum disorders, auditory, music, perception, cognition, development.

Music perception is intact in children with ASD

Introduction

Autism spectrum disorder (ASD) is a complex neurodevelopmental disorder characterized by social and communication impairments as well as restricted and repetitive behaviours (American Psychiatric Association, 2013). Atypical sensory perception is included in the domain of restricted and repetitive behaviors. While many individuals with ASD have impairments in processes required for speech perception, such as auditory filtering, phoneme categorisation, and multisensory integration (DePape et al., 2012), they often have preserved or even enhanced auditory-music skills (Ouimet et al., 2012) such as in pitch discrimination (Heaton, 2003, 2005**)** and pitch memory **(**Stanutz, Wapnick, & Burack, 2014). Thus, as a non-verbal model, music provides a unique way to study auditory processing in ASD. The study of sensory processing can help to better define individual differences in ASD and to refine sensory phenotypes.

However, relative to studies on social cognition and language, research remains quite limited on sensory processing in ASD, and particularly on auditory-music processing. Accordingly, the present study sought to assess music perception across a range of music tasks in children with ASD versus typical development (TD), as a function of differing cognitive abilities, age and symptom severity. Our ultimate goal is to better characterize auditory perception in children with ASD, and for these results to help guide auditory-based interventions to improve communication and social functioning in ASD.

Music perception in ASD

Studies on auditory-music processing in ASD are limited. Some work has found enhanced music perception particularly in terms of pitch processing in ASD. For example, people with ASD have shown enhanced processing in frequency discrimination (Jones et al., 2009), single tone pitch discrimination (Stanutz, Wapnick, & Burack, 2014; Bonnel et al., 2010; Heaton et al., 2008; O'Riordan & Passetti, 2006), and pitch identification (Heaton, Hermelin, & Pring, 1998). People with ASD have also shown enhanced detection of small pitch direction changes in interval tasks (Heaton, 2005), pitch categorization (Bonnel et al., 2003), disentangling pre-exposed pitch tones from chords (Altgassen et al. 2005), and contour identification (Jiang et al., 2015). Enhanced pitch memory has also been found in ASD for long-term melodic memory (Stanutz, Wapnick, & Burack, 2014), long-term pitch memory (Heaton et al., 2008), memory for unlabelled pre-exposed pitch tones (Heaton, 2003) and a greater incidence of absolute pitch in ASD (Bouvet et al., 2016; Mottron et al., 2013; DePape at al., 2012; Masataka, 2017). Findings for intact processing of auditory-musical and song material in ASD have also been reported at a neural level (Caria et al, 2011, Lai et al, 2012, Sharda et al, 2015). Such findings of enhanced processing in these music areas are consistent with the Enhanced Perceptual Functioning model of ASD that predicts enhanced processing of local (detailed) sensory features in ASD versus TD (Mottron et al., 2006), with intact processing of global (whole) sensory features.

However, enhanced musically-relevant processing in ASD has not always been replicated. For example, no performance differences were observed between ASD and TD on tasks of melodic global-local perception (Foster et al., 2016), pitch direction discrimination (Germain et al., in revision), pitch identification (Altgassen et al., 2005), or in studies involving harmonic priming (DePape et al., 2012), music structure processing (Bhatara et al., 2013) or contour discrimination (Jiang et al., 2015). Individuals with ASD also appear to perform the same as TD children in auditory-motor rhythm synchronization (Tryfon et al., 2017), although some studies have reported that people with ASD have reduced specialization in categorizing simpler meters prevalent in

Western music over more complex meters (DePape et al., 2012). This range of performance may be explained by various factors including different tasks used across the studies, along with the differing cognitive abilities, age and symptom severity of the ASD participants.

Taken together, studies suggest that auditory-music processing is intact overall in ASD, with some examples of enhanced processing of pitch information. However, to better characterize auditory-music processing in ASD, more research is required and in particular across a range of music perception tasks, and as a function of cognitive ability, age and symptom severity of ASD participants.

The effect of verbal and non-verbal cognitive abilities on music perception in ASD

One challenge to understanding music perception differences in ASD is to discern how variables other than ASD traits (such as verbal and non-verbal intelligence) influence music perception. Studies on the association between perception and cognition in ASD are key to better understand individual differences and to refine sensory phenotypes in ASD; however, few such studies exist. Verbal and non-verbal cognitive profiles in ASD are highly variable (Black et al., 2009; Charman et al., 2005; Farley et al., 2009; Joseph et al., 2002; Koyama, Tachimori, Osada, Takeda, & Kurita, 2007). For example, individuals with ASD often display uneven cognitive profiles relative to TD individuals (e.g., either having non-verbal or verbal IQ substantially higher than the other domain; Black et al., 2009; Joseph et al., 2002).

In TD, better performance on auditory tasks has been related to improved receptive language ability (Grube, Kumar, Cooper, Turton, & Griffiths, 2012; Mayer et al., 2016), but the status of such a link between auditory perception and verbal skills in ASD is not clear. For example, Mayer et al. (2016) found no association between auditory pitch discrimination and receptive vocabulary in ASD. In terms of non-verbal cognitive ability, some studies have revealed a connection between the block design task, a measure of nonverbal reasoning, and auditory skills such as pitch discrimination (Mayer et al., 2016), melodic discrimination (Stanutz, Wapnick, & Burack, 2014), and melodic memory ability (Heaton et al., 1998, Heaton, Williams, Cummins, & Happé, 2008; Stanutz et al., 2014). However, these findings have not always been replicated (Heaton et al., 2008; Meilleur et al., 2015).

Our laboratory recently found significant variability in performance on pitch and melodic discrimination tasks in both ASD and TD children that was predicted by nonverbal, but not verbal skills (Chowdhury et al., 2017). However, the stimuli in the Chowdhury et. al. study was not designed to function as naturalistic (ecologically valid) music, and the range of cognitive ability did not include individuals with lower IQ. Novel aims of the present work were to examine musical perception in association with verbal and non-verbal abilities across a broader range of more ecological musical tasks including melody, rhythm and memory tasks. In order to examine the effect of verbal and non-verbal abilities on music perception, we defined three samples of participants (see Table 1 below). A 'VIQ-matched' sample was designed to compare the TD group with a well-matched ASD group in order to minimize possible confounds due to differences in IQ level. A group comparison including a more representative variation of cognitive ability was also conducted, where a larger ASD group had a full range of VIQ and broader range of non-verbal IQ (by including children with moderate and mild levels of impairment), to determine if results found in the VIQ-matched sample would hold against a more representative ASD sample. A third 'ASD-only' sample examined music perception abilities with respect to verbal and non-verbal IQ, receptive vocabulary, age, and ASD symptom severity.

The effect of age on music perception in ASD

In addition to verbal and non-verbal cognitive abilities, other variables such as age may contribute to differences in music perception ability in ASD. Age predicts music perception ability in TD children from 6-8 years old (Peretz et al., 2013). In ASD, subtle developmental trends have been detected in auditory global-local processing whereby children with ASD perform better at younger ages (Foster et al., 2016). Similarly, one study also reported an improvement of fine pitch discrimination abilities in TD children from 5 to 14 years, whereas in ASD they were enhanced in childhood (6-14 years) and remained stable across development (Mayer, Hannent & Heaton, 2016). In addition, developmental differences have been found in ASD for auditory short-term memory which continues to develop to adulthood in TD, but stops prematurely in persons with ASD (Erviti et al., 2015). Brain imaging studies have also revealed age-related structural and functional neural differences between ASD and TD in areas related to language and auditory processing (Floris et al., 2016; Groen et al., 2011; Keller et al., 2007; Lange et al., 2015; Lee et al., 2007; Wan et al., 2012). Overall, some aspects of auditory-music perception, and in particular fine-grained pitch processing, appear to develop differently in ASD versus TD, but further study across a range of music tasks is required to better understand these developmental effects.

The effects of symptom severity on music perception in ASD

In addition to studying how development affects music perception in ASD, it is important to investigate how music perception might be linked to clinical severity in ASD. Such studies can help to better understand individual differences in ASD and to refine ASD phenotypes. However, there has been surprisingly little study on the connection between sensory perception and symptom severity in ASD. One recent study revealed a significant relationship between electrophysiological neural (EEG) indices of an audiovisual simple reaction time task and the severity of ASD symptoms, in a group of children and adolescents with ASD (Brandwein et al., 2015). While EEG responses on the audio-visual task predicted ASD severity, behavioral reaction times did not, indicating that EEG is a particularly sensitive metric to predict ASD symptoms. Moreover, the EEG neural responses and reaction time data did not predict auditory/visual sensitivities, as assessed by parent responses on the Short Sensory Profile (SSP) (McIntosh et al., 1999), a questionnaire on which parents/caregivers rate their child's reactions, preferences, and tendencies when confronted with everyday sensory stimuli and situations (Brandwein et al., 2015). No study has yet examined the potential link between music perception and ASD severity. The study of how music processing might be related to ASD clinical severity can possibly guide future auditory-musical based interventions in ASD.

Objectives and hypotheses

The objective of the present study was to better characterize auditory profiles by examining music perception across a range of music abilities in school-age children with ASD versus TD, and to measure how this music perception may vary based on cognitive abilities, age and ASD symptom severity. The first specific aim was to test the hypothesis that children with ASD would show intact or enhanced processing relative to TD across a range of music tasks including melodic pitch perception, rhythm discrimination and musical memory. The second aim was to test the hypothesis that music perception abilities in ASD would be related to non-verbal cognitive abilities, but not necessarily to verbal abilities (Chowdhury et al., 2017). The third aim was to test the hypothesis that performance would improve on music tasks as a function of age in TD, but not necessarily in ASD (Foster et al., 2016). The final aim was to test the hypothesis that music perception in ASD would be associated with symptom severity, with the prediction that any relationship between severity and music perception would be in the direction of group differences in performance.

Methods

Participants

Two groups of children participated in the present study: (a) 47 boys with ASD and (b) 23 TD boys, matched on age (mean age: 10.1, SD: 1.8 years, range: 6-12 years). Participants were recruited from laboratory databases and through the local community. Individuals with ASD were diagnosed by expert opinion (American Psychiatric Association, 2000, 2013), and diagnoses were supported by standard diagnostic measures (Autism Diagnostic Observation Schedule [ADOS] Lord et al., 1989; Autism Diagnostic Interview-Revised [ADI-R], Lord, Rutter, & Lecouteur, 1994) where available. Exclusion criteria for all children were a gestational age of 35 weeks or less, hearing impairment, or history of neurological or psychiatric illness. The Social Communication Questionnaire [SCQ] (Rutter, Bailey & Lord, 2003) is a screening test for entry into research in ASD and is modelled as a questionnaire version of the Autism Diagnostic Interview-Revised [ADI-R] (Lord, Rutter, & Couteur, 1994). A further inclusion criterion for the ASD group was an SCQ of 12 or above, consistent with an ASD diagnosis. Inclusion criteria for the TD group were an SCQ score below 12, and the absence of a family history of ASD. The study was approved by local University ethics committees. All guardians provided written informed consent and participants above the age of 14 years provided assent. All participants received a t-shirt or a gift card as compensation for their time.

The Montreal Battery for Evaluation of Musical Abilities (MBEMA)

In the present study, the Montreal Battery for the Evaluation of Musical Abilities MBEMA (Peretz et al., 2013) was used to assess a range of music perception abilities in ASD and TD school-age children. The MBEMA is a choice test battery for this purpose since it is an objective, short (~20 minutes) and child-friendly test battery of music perception that can be used in both TD and special populations, and across cultures (Peretz et al., 2013). The MBEMA has been described in detail elsewhere (Peretz et al., 2013) but briefly includes three types of tests: 1) melodic pitch (involving either a scale, interval, or contour pitch change), 2) rhythm, and 3) memory. In total, the task includes 30 unfamiliar melodies. 20 of these melodies are used on both the melodic pitch and rhythm tests, whereas the memory test uses 10 of the same melodies as the other two tests plus the remaining 10 melodies.

Melodies are presented in different keys and timbres to make the tests as engaging as possible. In the melodic pitch test, participants are asked to make a same-different judgement between two short melodies that may differ in the pitch of one note; this pitch change alters either the scale, interval or melodic contour. This test contained 10 “same” and 10 “different” trials. In the rhythm test, participants are asked to make a same-different judgement between two short melodies that may differ in rhythmic grouping. This test also contained 10 “same” and 10 “different” trials. In the memory test, participants are presented with a series of single melodies, 10 of which they heard in the previous tests, and 10 of which are new melodies. For each melody, participants are asked if they heard it before or not (see Figure 1). Trials in the MBEMA are not subject to a time limit, which make it suitable for testing children with ASD whose diagnosis may be comorbid with Attention Deficit Hyperactivity Disorder (ADHD).

The MBEMA was administered on a laptop computer using Presentation software (Neurobehavioral Systems, http://www.neurobs.com). Responses were recorded using the left and right buttons of a computer mouse. The stimuli were presented to the participants in a quiet room at a comfortable volume. Accuracy scores on the MBEMA were calculated as the percentage of correct responses in each task.

Figure 1

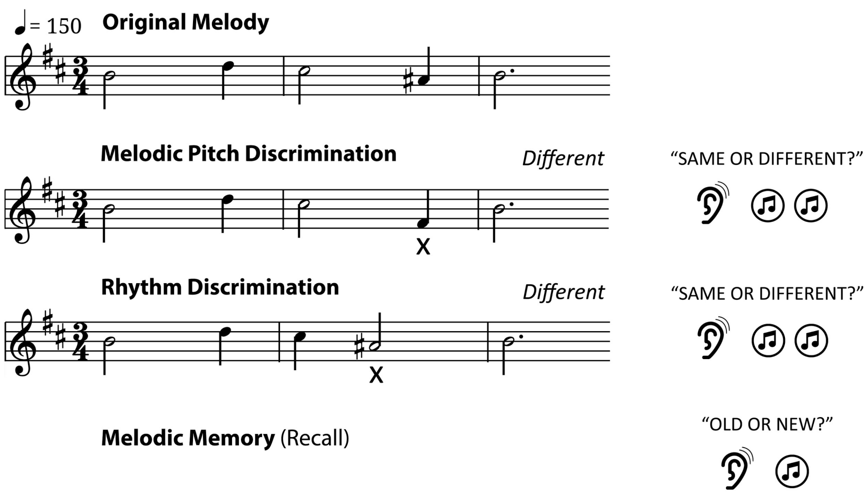

Figure 1. Example of one music stimulus as used in the three subtests of the MBEMA (adapted from Peretz et al., 2013). The standard stimulus is represented in the original, followed by a melodic alternate (violating the interval, contour or scale) and a rhythm alternate. The X indicates the changed note. The example can be heard at www.brams.umontreal.ca/short/mbea-child

Cognitive measures

An estimate of IQ abilities was obtained by the Wechsler Abbreviated Scale of Intelligence II (WASI-II; Wechsler, 2013) which provides Full-Scale (FSIQ), Verbal (VIQ) and Performance

(PIQ) scores. The VIQ sub-scale includes the Similarities subtest of verbal reasoning and concept formation, as well as the Vocabulary subtest of word knowledge and verbal concept formation. The PIQ sub-scale measures nonverbal cognitive abilities via the Blocks sub-test which assesses the ability to analyze and synthesize abstract visual stimuli, and the Matrix Reasoning Task which assesses the ability to identify the missing element that completes a pattern. Two participants in the VIQ-matched sample, three in the non-VIQ-matched sample and three in the ASD-only sample had already taken the Weschler's Intelligence Scale for Children IV or V (WISC-VI; Wechsler, 2003; WISC-V; Wechsler, 2014), in which case we used their WISC verbal composite score if it was recorded within 2 years of testing date. We ran the same analyses for each sample separately excluding these participants and it did not affect the results. Receptive vocabulary was measured using the Peabody Picture Vocabulary Test (PPVT-4) (Dunn & Dunn, 2007), where participants are presented with a word and four pictures and then asked to choose which picture best corresponds to a spoken word.

Symptom severity

Symptom severity in ASD was measured using total t-scores from the Social Responsiveness Scale (SRS-2) (Constantino et al., 2012). The SRS-2 is a norm-referenced parent-reported questionnaire used to identify the existence and severity of social symptoms characteristic of ASD.

Data Analyses

<u>Definition of samples of participants</u>

In order to examine the effect of IQ on music perception and memory abilities, we defined three overlapping samples of participants (see Table 1). In order to control for the effects of verbal IQ on the results, sample 1 ('VIQ-matched') included 25 ASD and 23 TD participants that were matched on VIQ (minimum VIQ of 90, mean VIQ 114.38). Participants were included only if they performed above chance across the three MBEMA music perception tasks. When evaluating the MBEMA's sensitivity and chance performance, Peretz et al. (2013) used the global MBEMA score with a cut-off of >50%. In the present study, a statistically based chance criterion for global MBEMA score was calculated by permutation test, yielding a cut-off of >64%. Following this criterion, 4 ASD and 2 TD children were excluded, leaving a sample of 21 ASD and 21 TD. In order to examine MBEMA results in a more representative sample of children with ASD versus TD, sample 2 (non-VIQ-matched) included 47 ASD and 23 TD participants with no minimum VIQ requirement (VIQ range 55-142), and no chance cut-off criterion for the MBEMA scores. In order to examine within-group effects in a representative ASD sample, sample 3 ('ASD only') included ASD participants (n=36) who had available data on all of the following: VIQ, PIQ, receptive vocabulary, and symptom severity scores. This sample had no minimum VIQ requirement (VIQ range 55-136), and no chance cut-off criterion for MBEMA scores.

Table 1

Participant Characteristics

	VIQ-matched sample			Non-VIQ matched sample			ASD-only Sample
	ASD (n=21)	TD (n=21)		ASD (n=47)	TD (n=23)		ASD (n=36)
	Mean (SD, Range)	**Mean** (SD, Range)	p	**Mean** (SD, Range)	**Mean** (SD, Range)	p	**Mean** (SD, Range)
Age	10.6 (1.6, 7-12)	9.8 (1.8, 7-12)	0.2	10.3 (1.8, 6-12)	9.7 (1.8, 7-12)	0.2	10.3 (1.8, 6-12)
FSIQ[a]	117.0 (15.1, 90-144)	122.2 (11.2, 100-141)	0.2	103.2 (18.6, 62-144)	120.6 (12.0, 100-141)	<0.001*	103.8 (18.6, 62-144)
PIQ[a]	119.4 (17.0, 91-148)	122.9 (15.41, 95-149)	0.5	112.1 (17.4, 72-148)	121.9 (15.2, 95-149)	0.03*	111.8 (17.1, 72-148)
VIQ[a]	113.6 (13.6, 91-136)	115.1 (12.0, 95-142)	0.7	96.4 (21.4, 55-136)	113.4 (12.9, 91-142)	<0.001*	96.7 (22.4, 55-136)
SCQ	19.0 (5.3, 12-35)	4.2 (2.5, 0-9)	<0.001*	19.9 (5.5, 8-35)	4.0 (2.53, 0-9)	<0.001*	20.2 (5.4, 8-35)
PPVT-4							96.7 (24.8, 42-145)
SRS-2							69.4 (9.1, 55-90)

Note. *SD=standard deviation; IQ=intelligence quotient; FSIQ= Full-Scale IQ, PIQ=Performance IQ, VIQ = Verbal IQ; SCQ= Social Communication Questionnaire; PPVT-4 = Peabody Picture Vocabulary Test 4; SRS-2 = Social Responsiveness Scale 2.*

[a] was measured using the Wechsler Abbreviated Scale of Intelligence (WASI)

**p<0.05*

Statistical analyses

Linear fixed effects models were used to evaluate the effect of group, IQ, age and their interactions on accuracy on the MBEMA tasks in both the VIQ-matched sample and the non-VIQ-sample, as shown below.

$$Accuracy_{Task} = \beta_0 + \beta_1*Group + \beta_2*FSIQ + \beta_3*Age + \beta_4*FSIQ*Group + \beta_5*Age*Group$$

where $Accuracy_{Task}$ is performance on one MBEMA task (melody, rhythm or melody). The model was tested for each MBEMA task separately in each analysis. Because 6 ASD participants only had FSIQ scores (PIQ scores missing) in the VIQ-matched sample, the sample size of the VIQ-matched sample would have been reduced from current N=21 to N=17 for the ASD group. We considered the cost of this sample size reduction too high and instead total IQ was examined via the FSIQ score for the VIQ-matched sample. We chose to use FSIQ as well in the non-VIQ-matched analysis in order to maintain coherence for answering our primary hypothesis testing music perception in ASD vs. TD. The influence of VIQ and PIQ scores was therefore examined in the larger ASD-only analysis described below.

The ASD-only sample was utilized to examine whether music perception performance was related to receptive vocabulary and symptom severity within the ASD group. In this analysis, terms for performance IQ and verbal IQ were included in order to obtain more precision about which aspect of IQ is related to music perception. For each MBEMA task we used a linear fixed effects model to test on the effect of verbal IQ (WASI-IV), performance IQ (WASI-IV), age, social symptom severity (SRS-2) and receptive vocabulary (PPVT-4) on MBEMA subscore:

$$\text{Accuracy}_{\text{Task}} = \beta_0 + \beta_1{*}\text{VIQ} + \beta_3{*}\text{PIQ} + \beta_4{*}\text{Age} + \beta_5{*}\text{SRS} + \beta_6{*}\text{PPVT}$$

PPVT and VIQ scores were correlated (r=.74), so out of caution a supplementary analysis was tested with the PPVT term removed, and the same results were found for VIQ, PIQ, Age and SRS. All continuous independent values were mean centered. Analyses were performed in R software (R Development Core Team, 2011) and significance was assessed using type III sum of squares at $p < 0.05$. Results are noted when p values pass a Bonferroni correction for multiple comparisons across the 3 MBEMA tests, i.e. $p < 0.0167$. Effect sizes are reported as partial eta squared (η_p^2; Lakens, 2013).

Results

MBEMA performance - ASD vs TD (Figure 2)

The results of the MBEMA performance comparisons for the VIQ-matched sample are shown in Figure 2. The accuracy scores did not differ between the ASD and TD group for melodic pitch discrimination ($F(1,36)=0.94$, $p=.34$, $\eta_p^2=.03$), rhythm discrimination ($F(1,36)=1.17$, $p=.29$, $\eta_p^2=.03$) or melodic pitch memory ($F(1,36)=0.03$, $p=.86$, $\eta_p^2<.01$) in this sample (Figure 2). Similar results were found in the non-VIQ-matched sample for melodic pitch discrimination ($F(1,64)=0.15$, $\eta_p^2<.01$) and melodic pitch memory ($F(1, 64)=0.90$, $p=.35$, $\eta_p^2=.01$). A group difference for rhythm discrimination failed to meet significance ($F(1,64)=3.38$, $p=.07$, $\eta_p^2=.05$).

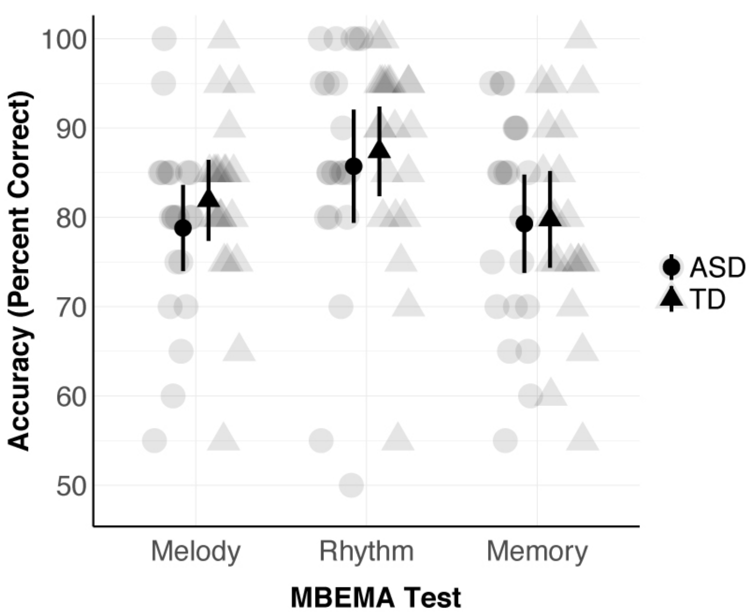

Figure 2. Mean task accuracy is equivalent between ASD and TD on each music perception task (VIQ-matched sample, all p>.05, bars represent +- 1 standard error)

Effect of cognitive measures on MBEMA performance - ASD and TD (Figure 3)

In the VIQ-matched sample, there were no significant main effects of full-scale IQ on melodic pitch discrimination ($F(1,36)=1.17$, $p=.23$, $\eta_p^2<.01$), rhythm discrimination ($F(1,36)=0.26$, $p=.61$, $\eta_p^2<.01$) or melodic memory ($F(1,36)=1.42$, $p=.24$, $\eta_p^2=.04$). There were no significant FSIQ*Group interactions on melodic pitch discrimination ($F(1,36)=1.08$, $p=.31$, $\eta_p^2<.01$), rhythm discrimination ($F(1,36)=0.19$, $p=.66$, $\eta_p^2<.01$) or melodic memory ($F(1,36)=0.61$, $p=.44$, $\eta_p^2=.02$) in this sample.

In the non-VIQ-matched sample, there was a significant main effect of FSIQ for rhythm discrimination ($F(1,64)=10.19$, $p=.002$, $\eta_p^2=.22$; Figure 3a) and melodic pitch discrimination ($F(1,64)=5.51$, $p=.02$, $\eta_p^2=.13$), though the latter p-value did not pass the Bonferroni correction. There was also a significant main effect of FSIQ for melodic memory ($F(1,64)=15.05$, $p<.001$, $\eta_p^2=.29$; Figure 3b). There were no significant FSIQ*Group interactions on melodic pitch discrimination ($F(1,64)=0.26$, $p=.61$, $\eta_p^2=.01$), rhythm discrimination ($F(1,64)=0.24$, $p=.62$, $\eta_p^2=.01$) or melodic memory ($F(1,64)=0.87$, $p=.36$, $\eta_p^2=.02$) in this sample.

In the ASD-only sample, there was a significant effect of PIQ on melodic pitch discrimination ($F(1,30)=18.74$, $p<.001$, $\eta_p^2=.38$; Figure 3c), rhythm discrimination ($F(1,30)=4.65$, $p=.04$, $\eta_p^2=.13$) and melodic memory ($F(1,30)=4.60$, $p=.04$, $\eta_p^2=.13$), and a significant effect of VIQ on rhythm discrimination ($F(1,30)=4.80$, $p=.04$, $\eta_p^2=.14$); however, these last three values do not pass the Bonferroni correction. There was no significant effect of receptive vocabulary on melodic pitch discrimination ($F(1,30)=0.41$, $p=.52$, $\eta_p^2=.01$), rhythm discrimination ($F(1,30)=0.44$, $p=.24$, $\eta_p^2=.05$) or melodic memory ($F(1,30)=0.36$, $p=.85$, $\eta_p^2<.01$).

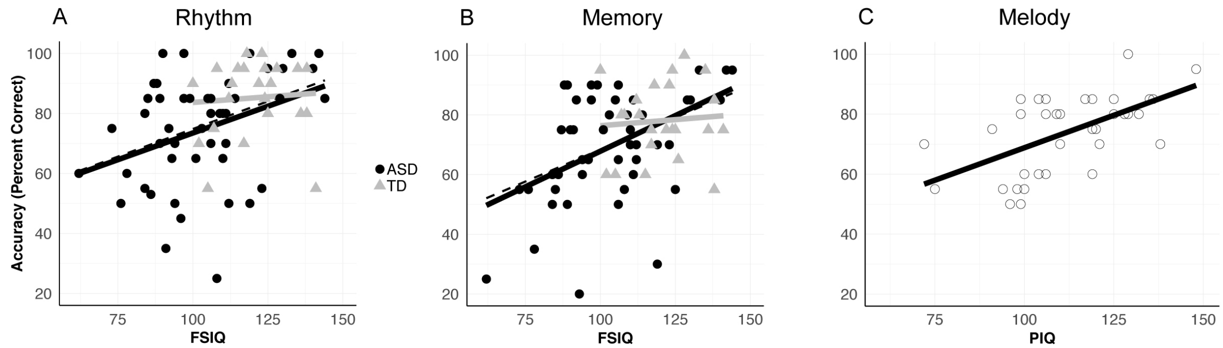

Figure 3. Music perception accuracy increases with cognitive abilities in ASD and TD. A) Rhythm discrimination increases with full-scale IQ (non-VIQ-matched sample, dotted line shows main effect across both groups, p<.002); B) Melodic memory increases with full-scale IQ (non-VIQ-matched sample, dotted line shows main effect across both groups, p<.001); C) Melodic pitch discrimination increases with performance IQ in ASD (ASD-only sample, p<.001).

Effect of age on MBEMA performance - ASD and TD (Figure 4)

In the VIQ-matched sample there was a significant main effect of age on accuracy scores for rhythm discrimination ($F(1,36)=6.61$, $p=.014$, $\eta_p^2=.18$, Figure 4b). There were no significant main effects of age on melodic pitch discrimination ($F(1,36)=0.16$, $p=.69$, $\eta p^2=.01$) or melodic memory ($F(1,36)=0.001$, $p=.98$, $\eta_p^2<.01$). There were no significant Age*Group interactions on melodic pitch discrimination ($F(1,36)=0.003$, $p=.96$, $\eta_p^2<.01$), rhythm discrimination ($F(1,36)=0.49$, $p=.49$, $\eta_p^2<.01$) or melodic memory ($F(1,36)=.51$, $p=0.48$, $\eta_p^2=.02$) in this sample. In the non-VIQ-matched sample, there was a significant main effect of age for melodic pitch discrimination ($F(1,64)=5.50$, $p<.02$, $\eta_p^2=.15$, Figure 4a), and rhythm discrimination ($F(1,64)=19.29$, $p<.001$, $\eta_p^2=.39$), however the former does not pass the Bonferroni correction. There was no significant main effect of age on melodic memory ($F(1,64)=0.03$, $p=.86$, $\eta_p^2<.01$). There was no significant Age*Group interaction on melodic pitch discrimination ($F(1,64)=0.11$, p=.74, η_p^2<.01), rhythm discrimination (F(1,64)=1.26, p=.61, η_p^2<.01) or melodic memory (F(1,64)=1.95, p=.17, η_p^2=.06) in this sample. In the ASD-only sample, there was a significant main effect of age on melodic pitch discrimination (F(1,30)=7.59, p=.01, η_p^2=.20) and rhythm discrimination (F(1,30)=10.92, p=.002, η_p^2=.27), but not for melodic memory (F(1,30)=0.05, p=.82, η_p^2<.01).

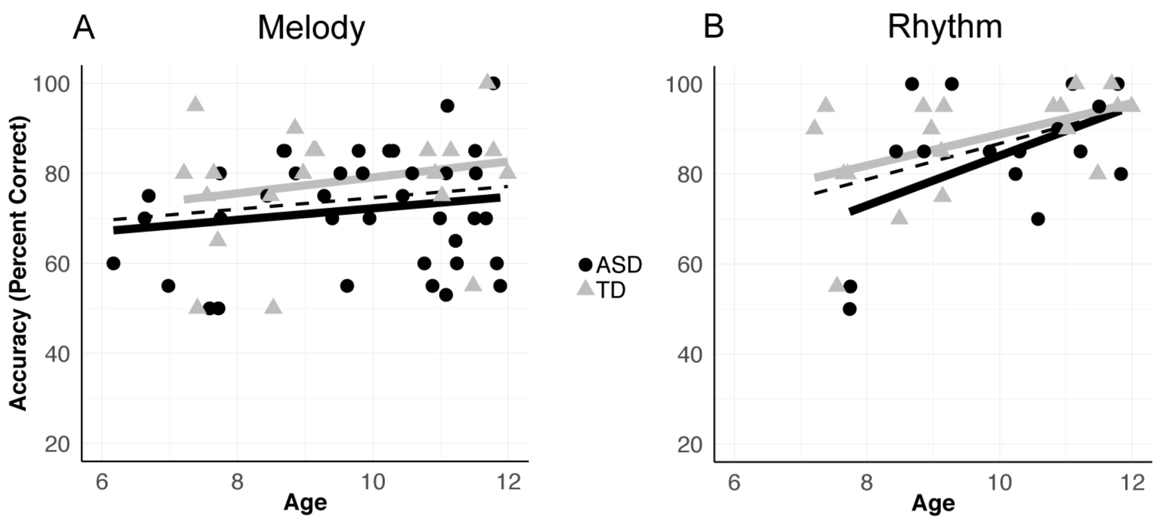

Figure 4. Melodic pitch discrimination and rhythm discrimination increase with age in ASD and TD. A) Melody task (non-VIQ-matched sample, dotted line shows main effect across both groups, p=.02); B) Rhythm task (VIQ-matched sample, dotted line shows main effect across both groups, p=.014).

Effect of ASD symptom severity on MBEMA performance (Figure 5)

There was no significant effect of symptom severity on the MBEMA tests of melodic pitch discrimination (F(1,30)=0.37, p=.85, η_p^2<.01), rhythm discrimination (F(1,30)=0.002, p=.96, η_p^2<.01) or melodic memory (F(1,30)=0.78, p=.38, η_p^2=.03) (Figure 5).

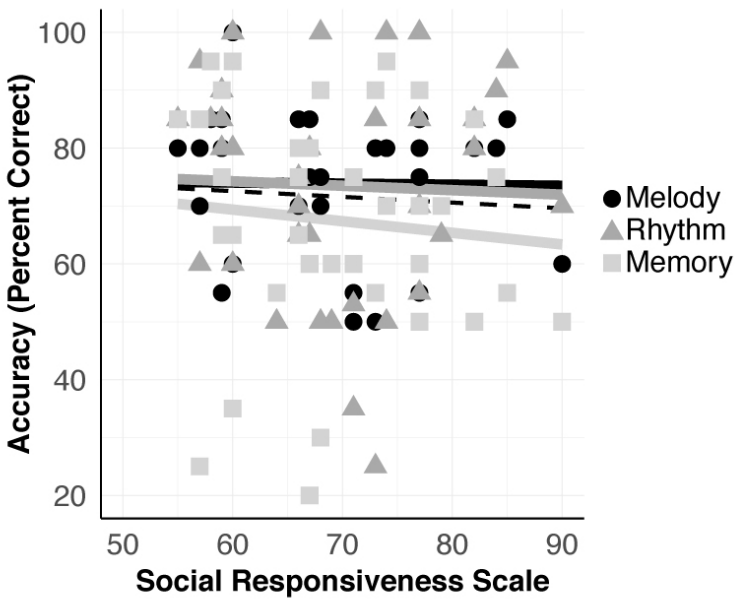

Figure 5. ASD symptom severity is not related to music perception in ASD (all p≥.38, 60-66 = mild, 66-75 = moderate, 75-90 = severe symptoms; Constantino et al., 2012).

Discussion

The main objective of the current study was to better characterize music perception abilities in ASD versus TD children, and to examine how this perceptual performance may vary as a function of cognitive abilities, age and ASD symptom severity. Taken together, findings suggest that music perception is intact in children with ASD and that music perception performance is related to non-verbal cognitive ability and age, but not to verbal cognitive ability or social symptom severity.

Analysis design

In the present study, we examined music perception in children with ASD versus TD using three different samples of participants. In order to minimize possible confounds due to differences in IQ level, a 'VIQ-matched' sample was designed to compare the TD group with a well-matched ASD group. Overall, the VIQ-matched ASD and TD samples performed similarly across the melodic, rhythmic and musical memory tests. In addition, we tested a 'non-VIQ-matched' sample to broaden the full-scale IQ criterion and to determine if results found in the VIQ-matched sample would hold against a more representative ASD sample (including children with lower IQ), and found similar results to the VIQ-matched sample. A third ASD-only sample tested MBEMA performance dependence on additional cognitive measures, age and symptom severity. Results are discussed in detail below.

Intact music perception in ASD - melody, rhythm, and memory

The first aim of the present study was to investigate music perception across a range of musical tasks in ASD versus TD. It was hypothesized that the ASD group would exhibit similar or enhanced performance versus TD in melodic pitch discrimination, rhythm discrimination and melodic memory. Results showed no performance differences between ASD and TD on either melodic pitch discrimination, rhythm discrimination or melodic memory. Music perception ability for the melodic pitch discrimination task was similar in both the VIQ-matched and non-VIQ-matched samples. These findings are consistent with previous research that found similar pitch discrimination abilities in children with ASD compared to TD (Germain et al., in revision; Jiang et al., 2015, Stanutz, Wapnick, & Burack, 2014; Bhatara et al., 2013; DePape et al., 2012). The present finding that ASD performed the same as TD on the rhythm discrimination task (in both

VIQ-matched and non-VIQ-matched samples) is consistent with findings of intact auditory-motor rhythm synchronization in ASD (Tryfon et al. 2017). Our findings suggest that fine-grained rhythm discrimination deficits found in DePape et al. (2012) do not extend to broader rhythm discrimination in children with ASD. Music perception capabilities for the melodic memory task were similar in both VIQ-matched and non-VIQ-matched samples. These findings coincide with the similar memory recall reported in ASD and TD when melodies were pre-exposed and not labelled (Heaton, 2003). Greater melodic memory has been shown in children with ASD of similar IQ for long-term memory tasks (Stanutz, Wapnick, & Burack, 2014). This distinction could be due to melodic memory relying more heavily on other cognitive functions such as working memory, which is typically developed in children with ASD (Craig et al., 2016; Kercood et al., 2014). Overall, the present findings are consistent with the Enhanced Perceptual Functioning model's principle that global processing in ASD is spared (Mottron et al., 2006), as children with ASD present here an adequate performance using a global processing strategy for detecting pitch and rhythm changes in an integrated music context. Present findings are not consistent with previous literature that finds enhanced music processing in ASD (Jiang et al., 2015; Stanutz, Wapnick, & Burack, 2014; Bonnel et al., 2010; Jones et al., 2009; Heaton et al., 2008; O'Riordan & Passetti, 2006; Altgassen et al. 2005; Heaton, 2005; Bonnel et al., 2003; Heaton, Hermelin, & Pring, 1998). This discrepancy is likely due to the more integrated nature of tasks in the MBEMA. Previous enhancements found in music perception tasks used fine grained aspects of music perception such as frequency discrimination, single tone pitch discrimination, contour, pitch direction, pitch identification, and disentangling pre-exposed pitch tones from chords.

Music perception is related to non-verbal cognitive abilities in ASD

The second aim of this research was to examine whether cognitive abilities are related to music perception. In order to further define which aspect of cognitive intelligence (verbal or non-verbal) is associated to which aspect of music perception (melody, rhythm or memory), and to avoid a potential confound between IQ and group in the non-VIQ-matched sample, we subsequently examined an ASD-only sample using verbal and non-verbal IQ as explanatory variables. We found that only melodic pitch discrimination increased with non-verbal ability in ASD. This is consistent with previous research showing a relationship between non-verbal abilities, such as the block-design task, with local pitch direction (Chowdhury et al., 2017) and pure tone pitch discrimination (Meilleur et al., 2014). The present study extends previous work to report a positive link between discriminating naturalistic music melodies and performance (i.e., non-verbal) IQ in children with ASD.

No relationship was found between receptive vocabulary and music perception performance in children with ASD, which is not consistent with findings from Mayer et al. (2016) that predict a positive relation between pitch discrimination and receptive vocabulary in children with ASD. However, pitch discrimination in Mayer et al. (2016) was not measured in the context of a melodic phrase. The present study describes the first positive relationship between full-scale IQ and music perception tasks (rhythm discrimination and melodic memory) in both ASD and TD. This relationship with full-scale IQ was found in the non-VIQ-matched sample only, suggesting that the effects of full-scale IQ on music perception may be more sensitive and relevant to children with ASD with lower verbal IQ ranges (55-90) than children with ASD of average IQ. Taken together, music perception is associated with non-verbal cognitive abilities, but not necessarily with verbal cognitive abilities.

Music perception ability increases with age in both ASD and TD children

The third aim was to examine if age affects music perception in children with ASD in a similar way to TD children. Rhythm discrimination accuracy increased with age in ASD and TD for all 3 samples (VIQ-matched, non-VIQ-matched, and ASD-only), as did melodic pitch discrimination in the ASD-only sample. Although melodic pitch discrimination and melodic memory were not associated with age in the smaller VIQ-matched sample, as a trend, music perception as a whole rather than rhythm discrimination in isolation is likely to be affected by age differences in ASD. In previous research, one study found developmental differences in ASD for short-term auditory memory between childhood and adulthood (Erviti et al., 2015). Our findings suggest that for short-term memory tasks involving music perception melodic memory does not vary as a function of age. This was the first study to explore the effects of age on melodic memory in children aged 6-12 years with ASD. A relationship between age and melodic memory may become apparent in a larger developmental window including adolescence. The trend that music perception as a whole tends to be related to age coincides with findings from Peretz and colleagues (2013). Note that no relation between the music tasks and age was found for the abbreviated version of MBEMA in Peretz et al. (2013). Our sample size was smaller than Peretz et al. (2013) but our age range was twice as wide, so our findings provide evidence that for children aged from 6-12 years old the abbreviated MBEMA is capable of detecting age related differences in music perception in TD similar to those found in when using the full MBEMA (Peretz et al., 2013). Furthermore, the abbreviated MBEMA can capture these differences for clinical populations, in particular for ASD.

Clinical severity does not affect music perception in children with ASD

The fourth aim was to examine if symptom severity was related to music perception in ASD. The study provides the first evidence that there is no relationship between social symptom severity and music perception in ASD. These results coincide with behavioral results showing that basic auditory processing does not predict symptom severity (Brandwein et al., 2015). Although no relationship between symptom severity and music perception was found here, results may be different at lower extremes of ASD severity. Furthermore, subpopulations of individuals having particular sound sensitivities may show different results. This finding helps to define the ASD phenotype by highlighting music perception as an ability that is not generally impaired in children with ASD as symptoms become more severe.

Study implications and future directions

This study provides a better characterization of auditory and musical profiles in children with ASD. In turn, this work helps to better define individual differences in ASD and to refine sensory phenotypes. To enhance the generalizability of results, future studies should include more representation of female ASD participants and individuals across a wider range of age and ASD severity. Finally, this work motivates future studies to examine the efficacy of auditory-musical interventions in ASD.

Conclusions

The present study provides evidence for intact music perception abilities in children with ASD across a range of music tasks including melody and rhythm discrimination as well as memory. This research extends previous work in important ways by providing new evidence for a relationship between music perception and non-verbal cognitive ability in ASD in particular, and a better understanding of the connection between music perception, development and clinical profiles in ASD.

General Discussion

The main objective of this thesis was to assess music perception in children with ASD versus TD across a range of music tasks, and over varying levels of cognitive abilities, age and ASD symptom severity. Taken together, findings suggest that music perception is intact in children with ASD and that it is related to non-verbal cognitive ability and age, but not to verbal cognitive ability or social symptom severity.

More specifically, findings revealed that:

1. There were no performance differences between ASD and TD on any of the measures of music perception (melody, rhythm, memory). Thus, school-age children with ASD and average IQ demonstrated intact music perception across a range of abilities.
2. Non-verbal abilities predicted performance in melodic pitch discrimination in ASD, but verbal abilities did not.
3. Age predicted rhythm discrimination in all three samples (VIQ-matched, non-VIQ-matched, and ASD-only), as did melodic pitch discrimination in the ASD-only sample.
4. There was no relationship between social symptom severity and music perception in children with ASD.

Contributions of this master's thesis to research in music perception in ASD

The overall aim of the present research was to better characterize sensory processing in the auditory domain in both ASD and TD, with a special focus on music perception and the effects of verbal and non-verbal cognitive abilities as well as age and symptom severity on performance.

First, our findings further our knowledge on sensory processing and auditory-musical processing in particular in ASD. Our findings of intact music processing in ASD expand on past reports showing no performance differences between ASD and TD groups across different domains (Altgassen et al., 2005; DePape et al., 2012; Bhatara et al., 2013; Jiang et al., 2015; Foster et al., 2016; Germain et al., 2017; Tryfon et al., 2017). These findings of preserved perceptual abilities in ASD provide support for the idea that there may be subgroups within the ASD that have "islets of ability," (Shah & Frith, 1983), or "splinter skills" (Heaton et al., 2008), thereby showing similar processing styles to TD. Taken together, these findings can help to refine better-targeted auditory-musical interventions in ASD and other special populations. For instance, children with ASD are likely to experience similar levels of intrinsic motivation when participating in existing music activities organized for typically developing children.

Second, our findings serve to better understand the connection between perception and cognition in ASD. Specifically, results revealed a significant association between cognitive ability and music perception in ASD and TD. Higher scores on the full-scale IQ predicted better music perception across both groups. We further explored the effects of verbal versus non-verbal cognitive ability in order to assess their respective contribution to variation in music perception in ASD. Our findings revealed a significant association between non-verbal reasoning and performance in pitch perception in ASD. Higher scores on the PIQ tasks predicted performance on melodic pitch discrimination. Although there has been limited research examining this association in the past (Chowdhury et al., 2017), the present results confirm that non-verbal ability (but not verbal ability) was related to pitch perception in ASD and that these findings extend to naturalistic (ecologically valid) stimuli.

Third, our findings shed light on the development of music perception abilities in both ASD and TD children. Specifically, results revealed a significant relation between age and music perception, particularly for melodic pitch perception and rhythm perception in ASD. Previous literature from our laboratory pointed towards the possibility that age affects certain aspects of music perception in ASD (Germain et al., in revision; Foster et al., 2016), and the present findings help confirm this association especially for melodic pitch discrimination and rhythm discrimination in ASD. Present findings also confirm that age predicts music perception in TD as previously found by Peretz et al. (2013), with an added caveat in that study that age was related to music perception only in the full MBEMA version and not the abbreviated version. The sample size was larger in Peretz et al. (2013) but our age range was twice as wide, so our findings support that the abbreviated MBEMA is capable of detecting age related differences in music perception in TD similar to those found in when using the full MBEMA for ages 6-12 years old (Peretz et al., 2013). Furthermore, the abbreviated MBEMA can detect these age differences for clinical populations, in particular for ASD. Taken together, these findings suggest that accuracy of music perception increases with age in ASD, especially for melodic pitch perception and rhythm discrimination.

Fourth, our findings inform us on the connection between music perception and ASD symptom severity. Specifically, results did not show any association between social symptom severity and music perception. These findings support behavioral results by Brandwein et al. (2015) that show no relation between auditory perception tasks and symptom severity.

Future directions

Novel features of the present work included: 1) the examination of music perception in ASD across a range of music tasks, 2) cognitive ability, 3) age and 4) symptom severity, as well as inclusion of a more representative range of low-IQ ASD participants across a wider IQ spectrum (i.e., including minimally verbal individuals). Our findings show that music perception can be intact even in minimally verbal children with ASD. In order to eliminate any confound with IQ, we recommend that future studies additionally compare music perception in children with lower IQ profiles but no ASD diagnosis. Furthermore, given that age was measured over a small developmental range in this study, future studies should include a longitudinal design and an age range extending to adulthood to better understand the developmental trajectory of auditory-musical profiles in ASD versus TD. Symptom severity was assessed here using parent reported measures over a wide range of clinical severity. Future studies will benefit from including individuals with more severe symptomology and use direct behavioral measures such as video-coding. Finally, this work motivates future research to examine potential auditory-musical based interventions in ASD and other special populations.

Conclusions

The main goal of this thesis was to examine music perception in ASD across a range of music perception tasks and types of cognitive abilities, age and symptom severity. The findings provide support for preserved music perception in school-aged children with ASD. The present study also supports existing literature linking auditory perception to cognitive abilities, further highlighting a potential association between auditory pitch perception and non-verbal abilities (rather than verbal skills) in ASD and TD. More specifically, better non-verbal abilities predict better auditory perception in naturalistic melodic pitch discrimination in ASD. These findings expand our knowledge on how sensory perception can vary across different levels of processing, and in turn, encourages future studies to include carefully examined samples of individuals with ASD expressing a wide range of abilities. In sum, a deeper comprehension of individual differences in sensory perception in ASD may not only contribute to refine perceptual-cognitive phenotypes in ASD, but may also lead to more targeted auditory-musical interventions in ASD and other special populations.

References

Altgassen, M., Kliegel, M., & Williams, T. I. (2005). Pitch perception in children with autistic spectrum disorders. *The British Journal of Developmental Psychology*, *23*, 543–558. https://doi.org/10.1348/026151005X26840

American Psychiatric Association. (2013). *DSM-V*. *American Journal of Psychiatry*. https://doi.org/10.1176/appi.books.9780890425596.744053

American Psychiatric Association. (2000). American Psychiatric Association: Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition, Text Revision. *American Psychiatric Association*. https://doi.org/10.1176/appi.books.9780890423349

Bhatara, A., Quintin, E.-M., Fombonne, E., & Levitin, D. J. (2013). Early Sensitivity to Sound and Musical Preferences and Enjoyment in Adolescents With Autism Spectrum Disorders. *Psychomusicology: Music, Mind & Brain*, *23*(2), 100–108. https://doi.org/10.1037/a0033754

Black, D. O., Wallace, G. L., Sokoloff, J. L., & Kenworthy, L. (2009). Brief report: IQ split predicts social symptoms and communication abilities in high-functioning children with autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *39*(11), 1613–1619. https://doi.org/10.1007/s10803-009-0795-3

Bonnel, A., McAdams, S., Smith, B., Berthiaume, C., Bertone, A., Ciocca, V., … Mottron, L. (2010). Enhanced pure-tone pitch discrimination among persons with autism but not Asperger syndrome. *Neuropsychologia*, *48*(9), 2465–2475. https://doi.org/10.1016/j.neuropsychologia.2010.04.020

Bonnel, A., Mottron, L., Peretz, I., Trudel, M., Gallun, E., & Bonnel, A.-M. (2003). Enhanced pitch sensitivity in individuals with autism: a signal detection analysis. *Journal of Cognitive Neuroscience*, *15*(2), 226–235. https://doi.org/10.1162/089892903321208169

Bono, M. A., Daley, T., & Sigman, M. (2004). Relations among joint attention, amount of intervention and language gain in autism. *Journal of Autism and Developmental Disorders*, *34*(5), 495–505. https://doi.org/10.1007/s10803-004-2545-x

Bouvet, L., Mottron, L., Valdois, S., & Donnadieu, S. (2016). Auditory Stream Segregation in Autism Spectrum Disorder: Benefits and Downsides of Superior Perceptual Processes. *Journal of Autism and Developmental Disorders*, *46*(5), 1553–1561. https://doi.org/10.1007/s10803-013-2003-8

Brandwein, A. B., Foxe, J. J., Butler, J. S., Frey, H. P., Bates, J. C., Shulman, L. H., & Molholm, S. (2015). Neurophysiological Indices of Atypical Auditory Processing and Multisensory Integration are Associated with Symptom Severity in Autism. *Journal of Autism and Developmental Disorders*, *45*(1), 230–244. https://doi.org/10.1007/s10803-014-2212-9

Caria, A., Venuti, P., & De Falco, S. (2011). Functional and dysfunctional brain circuits underlying emotional processing of music in autism spectrum disorders. *Cerebral Cortex*, *21*(12), 2838–2849. https://doi.org/10.1093/cercor/bhr084

Charman, T., Pickles, A., Simonoff, E., Chandler, S., Loucas, T., & Baird, G. (2011). IQ in children with autism spectrum disorders: Data from the Special Needs and Autism Project (SNAP). *Psychological Medicine*, *41*(3), 619–627. https://doi.org/10.1017/S0033291710000991

Charman, T., Taylor, E., Drew, A., Cockerill, H., Brown, J. A., & Baird, G. (2005). Outcome at 7 years of children diagnosed with autism at age 2: Predictive validity of assessments conducted at 2 and 3 years of age and pattern of symptom change over time. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, *46*(5), 500–513. https://doi.org/10.1111/j.1469-7610.2004.00377.x

Chowdhury, R.*, Sharda, M.*, Foster, N.E., Germain, E., Tryfon, A., Doyle-Thomas, K.A.R., Anagnostou, E., and Hyde, K.L. (2017). Auditory Pitch Perception in Autism Spectrum Disorder is associated with Superior Non-verbal Abilities. *Perception*. *46(11)*[*co-first authors]. https://doi.org/10.1177/0301006617718715

Constantino, J. (2012). Social Responsiveness Scale (SRS-2). *Western Psychological Services*, 3–5. https://doi.org/10.1007/978-1-4419-1698-3_296

Craig, F., Margari, F., Legrottaglie, A. R., Palumbi, R., de Giambattista, C., & Margari, L. (2016). A review of executive function deficits in autism spectrum disorder and attention-deficit/hyperactivity disorder. *Neuropsychiatric Disease and Treatment*. https://doi.org/10.2147/NDT.S104620

DePape, A.-M. R., Hall, G. B. C., Tillmann, B., & Trainor, L. J. (2012). Auditory Processing in High-Functioning Adolescents with Autism Spectrum Disorder. *PLoS ONE*, *7*(9), e44084. https://doi.org/10.1371/journal.pone.0044084

Dunn, L. M., & Dunn, D. M. (2007). Peabody Picture Vocabulary Test,. *Summary*, *30*(January), 1–8. https://doi.org/10.1037/t15144-000

Eigsti, I. M., & Fein, D. A. (2013). More is less: Pitch discrimination and language delays in children with optimal outcomes from autism. *Autism Research*, *6*(6), 605–613. https://doi.org/10.1002/aur.1324

Erviti, M., Semal, C., Wright, B. A., Amestoy, A., Bouvard, M. P., & Demany, L. A. I.-O. http://orcid. org/000.-0001-5549-9628. (2015). A late-emerging auditory deficit in autism. *Neuropsychology*, *29*(3), 454–462. https://doi.org/http://dx.doi.org/10.1037/neu0000162

Farley, M. A., McMahon, W. M., Fombonne, E., Jenson, W. R., Miller, J., Gardner, M., … Coon, H. (2009). Twenty-year outcome for individuals with autism and average or near-average cognitive abilities. *Autism Research*, *2*(2), 109–118. https://doi.org/10.1002/aur.69

Floris, D. L., Lai, M. C., Auer, T., Lombardo, M. V., Ecker, C., Chakrabarti, B., … Suckling, J. (2016). Atypically rightward cerebral asymmetry in male adults with autism stratifies individuals with and without language delay. *Human Brain Mapping*, *37*(1), 230–253. https://doi.org/10.1002/hbm.23023

Foster, N. E. V, Ouimet, T., Tryfon, A., Doyle-Thomas, K., Anagnostou, E., & Hyde, K. L. (2016). Effects of Age and Attention on Auditory Global–Local Processing in Children with Autism Spectrum Disorder. *Journal of Autism and Developmental Disorders*, *46*(4), 1415–1428. https://doi.org/10.1007/s10803-015-2684-2

Frith, U., Happé, F., & Happe, F. (2005). Autism spectrum disorder. *Current Biology*, *15*(19), R786-90. https://doi.org/10.1016/j.cub.2005.09.033

Germain, E.*, Sharda, M.*, Foster, N.E., Chowdhury, R., Tryfon, A., Doyle-Thomas, K.A.R., Anagnostou, E., and Hyde, K.L. Pitch direction perception and auditory global local processing in autism and typical development. (in revision) [*co-first authors]

Groen, W. B., Buitelaar, J. K., van der Gaag, R. J., & Zwiers, M. P. (2011). Pervasive microstructural abnormalities in autism: A DTI study. *Journal of Psychiatry and Neuroscience*, *36*(1), 32–40. https://doi.org/10.1503/jpn.090100

Grube, M., Kumar, S., Cooper, F. E., Turton, S., & Griffiths, T. D. (2012). Auditory sequence analysis and phonological skill. *Proceedings of the Royal Society B: Biological Sciences*, *279*(1746), 4496–4504. https://doi.org/10.1098/rspb.2012.1817

Heaton, P. (2005). Interval and contour processing in autism. *Journal of Autism and Developmental Disorders*, *35*(6), 787–793. https://doi.org/10.1007/s10803-005-0024-7

Heaton, P. (2003). Pitch memory, labelling and disembedding in autism. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, *44*(4), 543–551. https://doi.org/10.1111/1469-7610.00143

Heaton, P., Hermelin, B., & Pring, L. (1998). Autism and Pitch Processing : A Precursor for Savant Musical Ability ? *Source : Music Perception : An Interdisciplinary Journal*, *15*(3), 291–305. https://doi.org/10.2307/40285769

Heaton, P., Hudry, K., Ludlow, A., & Hill, E. (2008). Superior discrimination of speech pitch and its relationship to verbal ability in autism spectrum disorders. *Cognitive Neuropsychology*, *25*(6), 771–782. https://doi.org/10.1080/02643290802336277

Heaton, P., Williams, K., Cummins, O., & Happé, F. (2008). Autism and pitch processing splinter skills. *Autism*, *12*(2), 203–219. https://doi.org/10.1177/1362361307085270

Jiang, J., Liu, F., Wan, X., & Jiang, C. (2015). Perception of Melodic Contour and Intonation in Autism Spectrum Disorder: Evidence From Mandarin Speakers. *Journal of Autism and Developmental Disorders*, *45*(7), 2067–2075. https://doi.org/10.1007/s10803-015-2370-4

Jones, C. R. G., Happ??, F., Baird, G., Simonoff, E., Marsden, A. J. S., Tregay, J., … Charman, T. (2009). Auditory discrimination and auditory sensory behaviours in autism spectrum disorders. *Neuropsychologia*, *47*(13), 2850–2858. https://doi.org/10.1016/j.neuropsychologia.2009.06.015

Joseph, R. M., Tager-Flusberg, H., & Lord, C. (2002). Cognitive profiles and social-communicative functioning in children with autism spectrum disorder. *Journal of Child Psychology and Psychiatry*, *43*(6), 807–821. https://doi.org/10.1111/1469-7610.00092

Kanner, L., Rodriguez, A., & Ashenden, B. (1972). How far can autistic children go in matters of social adaptation? *Journal of Autism and Childhood Schizophrenia*, *2*(1), 9–33. https://doi.org/10.1007/BF01537624

Keller, T. A., Kana, R. K., & Just, M. A. (2007). A developmental study of the structural integrity of white matter in autism. *NeuroReport*, *18*(1), 23–27. https://doi.org/10.1097/01.wnr.0000239965.21685.99

Kercood, S., Grskovic, J. A., Banda, D., & Begeske, J. (2014). Working memory and autism: A review of literature. *Research in Autism Spectrum Disorders*. https://doi.org/10.1016/j.rasd.2014.06.011

Koyama, T., Tachimori, H., Osada, H., Takeda, T., & Kurita, H. (2007). Cognitive and symptom profiles in Asperger's syndrome and high-functioning autism. *Psychiatry and Clinical Neurosciences*, *61*(1), 99–104. https://doi.org/10.1111/j.1440-1819.2007.01617.x

Lai, G., Pantazatos, S. P., Schneider, H., & Hirsch, J. (2012). Neural systems for speech and song in autism. *Brain*, *135*(3), 961–975. https://doi.org/10.1093/brain/awr335

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. *Frontiers in Psychology*, *4*(NOV). https://doi.org/10.3389/fpsyg.2013.00863

Lange, N., Travers, B. G., Bigler, E. D., Prigge, M. B. D., Froehlich, A. L., Nielsen, J. A., … Lainhart, J. E. (2015). Longitudinal Volumetric Brain Changes in Autism Spectrum Disorder Ages 6-35 Years. *Autism Research*, *8*(1), 82–93. https://doi.org/10.1002/aur.1427

Lee, P. S., Foss-Feig, J., Henderson, J. G., Kenworthy, L. E., Gilotty, L., Gaillard, W. D., & Vaidya, C. J. (2007). Atypical neural substrates of Embedded Figures Task performance in children with Autism Spectrum Disorder. *NeuroImage*, *38*(1), 184–193. https://doi.org/10.1016/j.neuroimage.2007.07.013

Loomes, R., Hull, L., & Mandy, W. P. L. (2017). What Is the Male-to-Female Ratio in Autism Spectrum Disorder? A Systematic Review and Meta-Analysis. *Journal of the American Academy of Child and Adolescent Psychiatry*. https://doi.org/10.1016/j.jaac.2017.03.013

Lord, C., Rutter, M., & Couteur, A. L. (1994). Autism diagnostic interview-revised: A revised version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders. *Journal of Autism and Developmental Disorders*, *24*(5), 659–685. https://doi.org/10.1007/BF02172145

Lord, C., Rutter, M., Goode, S., Heemsbergen, J., Jordan, H., Mawhood, L., & Schopler, E. (1989). Austism diagnostic observation schedule: A standardized observation of communicative and social behavior. *Journal of Autism and Developmental Disorders*, *19*(2), 185–212. https://doi.org/10.1007/BF02211841

Luyster, R. J., Kadlec, M. B., Carter, A., & Tager-Flusberg, H. (2008). Language assessment and development in toddlers with autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *38*(8), 1426–1438. https://doi.org/10.1007/s10803-007-0510-1

McIntosh, D. N., Miller, L. J., Shyu, V., & Dunn, V. (1999). Short Sensory Profile. In *Sensory Profile user's manual* (pp. 59–73).

Masataka, N. (2017). Neurodiversity, giftedness, and aesthetic perceptual judgment of music in children with autism. *Frontiers in Psychology*, *8*(SEP). https://doi.org/10.3389/fpsyg.2017.01595

Mayer, J. L., Hannent, I., & Heaton, P. F. (2016). Mapping the Developmental Trajectory and Correlates of Enhanced Pitch Perception on Speech Processing in Adults with ASD. *Journal* *of Autism and Developmental Disorders*, *46*(5), 1562–1573. https://doi.org/10.1007/s10803-014-2207-6

Mayes, S. D., & Calhoun, S. L. (2003). Analysis of WISC-III, Stanford-Binet:IV, and academic achievement test scores in children with autism. *Journal of Autism and Developmental Disorders*, *33*(3), 329–341. https://doi.org/10.1023/A:1024462719081

Meilleur, A. A. S., Berthiaume, C., Bertone, A., & Mottron, L. (2014). Autism-specific covariation in perceptual performances: “g” or “p” Factor? *PLoS ONE*, *9*(8). https://doi.org/10.1371/journal.pone.0103781

Meilleur, A. A. S., Jelenic, P., & Mottron, L. (2015). Prevalence of Clinically and Empirically Defined Talents and Strengths in Autism. *Journal of Autism and Developmental Disorders*, *45*(5), 1354–1367. https://doi.org/10.1007/s10803-014-2296-2

Mottron, L., Bouvet, L., Bonnel, A., Samson, F., Burack, J. A., Dawson, M., & Heaton, P. (2013). Veridical mapping in the development of exceptional autistic abilities. *Neuroscience and Biobehavioral Reviews*. https://doi.org/10.1016/j.neubiorev.2012.11.016

Mottron, L., Dawson, M., Souli??res, I., Hubert, B., & Burack, J. (2006). Enhanced perceptual functioning in autism: An update, and eight principles of autistic perception. *Journal of Autism and Developmental Disorders*. https://doi.org/10.1007/s10803-005-0040-7

O’Riordan, M., & Passetti, F. (2006). Discrimination in autism within different sensory modalities. *Journal of Autism and Developmental Disorders*, *36*(5), 665–675. https://doi.org/10.1007/s10803-006-0106-1

Ouimet, T., Foster, N. E. V, Tryfon, A., & Hyde, K. L. (2012). Auditory-musical processing in autism spectrum disorders: A review of behavioral and brain imaging studies. *Annals of the*

New York Academy of Sciences, *1252*(1), 325–331. https://doi.org/10.1111/j.1749-6632.2012.06453.x

Peretz, I., Gosselin, N., Nan, Y., Caron-Caplette, E., Trehub, S. E., & Béland, R. (2013). A novel tool for evaluating children's musical abilities across age and culture. *Frontiers in Systems Neuroscience*, *7*, 30. https://doi.org/10.3389/fnsys.2013.00030

R Foundation for Statistical Computing, Vienna, A. I. 3-900051-07-0. (2011). R Development Core Team. *R: A Language and Environment for Statistical Computing*, *55*, 275–286. Retrieved from http://www.r-project.org/

Rutter M, Bailey A & Lord C (2003). The Social Communication Questionnaire. Los Angeles: Western Psychological Services

Shah, A., & Frith, U. (1993). Why do autistic individuals show superior performance on the block design task? *Journal of Child Psychology and Psychiatry and Allied Disciplines*, *34*(8), 1351–1364. https://doi.org/10.1111/j.1469-7610.1993.tb02095.x

Shah, A., & Frith, U. (1983). An islet of ability in autistic children: a research note. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *24*(4), 613–620. https://doi.org/10.1111/1469-7610.ep11422546.

Sharda, M., Midha, R., Malik, S., Mukerji, S., & Singh, N. C. (2015). Fronto-Temporal connectivity is preserved during sung but not spoken word listening, across the autism spectrum. *Autism Research*, *8*(2), 174–186. https://doi.org/10.1002/aur.1437

Stanutz, S., Wapnick, J., & Burack, J. (2014). Pitch discrimination and melodic memory in children with autism spectrum disorders. *Autism*, *18*(2), 137–147.

Tryfon, A., Foster, N. E., Ouimet, T., Doyle-Thomas, K., Anagnostou, E., Sharda, M., & Hyde, K. L. (2017). Auditory-motor rhythm synchronization in children with autism spectrum disorder. *Research in Autism Spectrum Disorders*, *35*, 51–61. https://doi.org/10.1016/j.rasd.2016.12.004

U.S. Department of Health and Human Services. (2014). Prevalence of autism spectrum disorder among children aged 8 years - autism and developmental disabilities monitoring network, 11 sites, United States, 2010. *Morbidity and Mortality Weekly Report. Surveillance Summaries (Washington, D.C. : 2002)*, *63*(2), 1–21. https://doi.org/24670961

Wan, C. Y., Marchina, S., Norton, A., & Schlaug, G. (2012). Atypical hemispheric asymmetry in the arcuate fasciculus of completely nonverbal children with autism. *Annals of the New York Academy of Sciences*, *1252*(1), 332–337. https://doi.org/10.1111/j.1749-6632.2012.06446.x

Wechsler, D. (2003). Wechsler intelligence scale for children–Fourth Edition (WISC-IV). *San Antonio, TX: The Psychological Corporation*. Retrieved from https://www.pearsonassessments.com/HAIWEB/Cultures/en-us/Productdetail.htm?Pid=015-8979-044&Mode=resource%5Cnhttp://www.pearsonclinical.com/psychology/products/100000310/wechsler-intelligence-scale-for-children-fourth-edition-wisciv.html?Pid=015-8979-044&Mo

Wechsler, D. (1999). *Wechsler Abbreviated Scale of Intelligence (WASI). Harcourt. Assessment: London.*

Wechsler, D. (2011). *Wechsler Abbreviated Scale of Intelligence--Second Edition*. *Wechsler Abbreviated Scale of Intelligence--Second Edition (WASI-II)*.

Wechsler, D. (2013). WASI -II: Wechsler abbreviated scale of intelligence - second edition. *Journal of Psychoeducational Assessment*, *31*(3), 337–41. https://doi.org/10.1177/0734282912467756

Wechsler, D. (2014). Wechsler intelligence scale for children–Fifth Edition (WISC-V). *San Antonio, TX: The Psychological Corporation*. Retrieved from https://www.pearsonclinical.com/psychology/products/100000771/wechsler-intelligence-scale-for-childrensupsupfifth-edition--wisc-v.html